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Tandem Optical Sensors to Assist in Runway Incursion Prevention

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Introduction

- FAA tasked to develop and execute a surface technology assessment program aimed at reducing incidence of runway incursions; portions of this directly supported by the Volpe Center

- FAA defines a runway incursion as “Any occurrence at an airport involving an aircraft, vehicle, person, or object on the ground that creates a collision hazard or results in loss of separation with an aircraft taking off, intending to take off, landing or intending to land.”

- FAA exploring various surface surveillance technologies as a means in preventing runway incursions

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Introduction

- Air traffic controller is responsible for assuring safe separation on runways and orderly movement of A/C on taxiways

- Process is dependent on visual observation of A/C and ground vehicle movements; interactions between A/C on final approach and A/C or vehicles on the runway must be rapidly assessed

- Low visibility (night, poor weather) dramatically impedes controllers’ ability to safely direct aircraft on the surface

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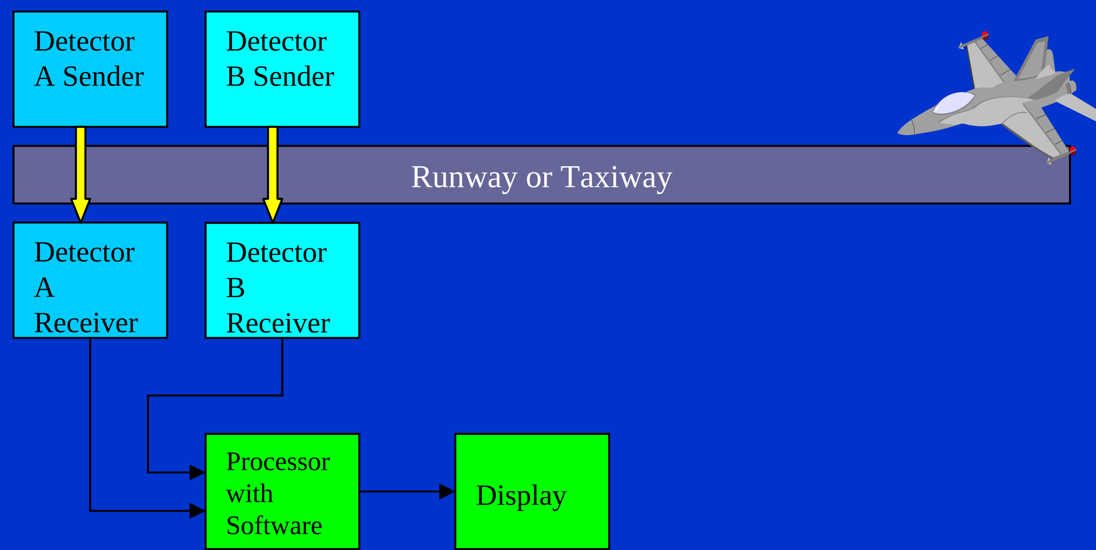
Concept

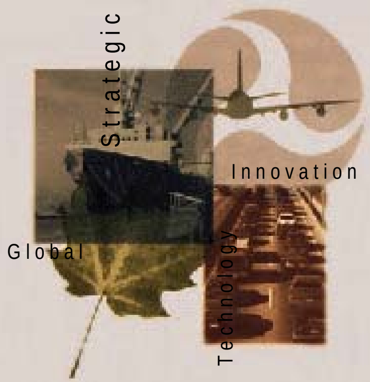


- Optical system using 2 sets of beams and detectors at chokepoints may aid in detection and tracking of taxiing A/C and vehicles on airport surface

- Portions of this concept have independently been successfully implemented and subsequently tested

Concept (cont.)

- Prototype software determines the following:
  - Velocity: calculated using known distance between Detector A and Detector B and measured time from nose wheel reaching 2nd detector after crossing the 1st averaged with same calculation performed using landing gear's main mounts
  - Wheelbase: calculated using vehicle's speed and amount of time required for each set of wheels to cross each detector
  - A/C type: determined by A/C's or truck's wheelbase; calculated using vehicle's speed and time required for each set of wheels to reach 1st detector; then compared with database



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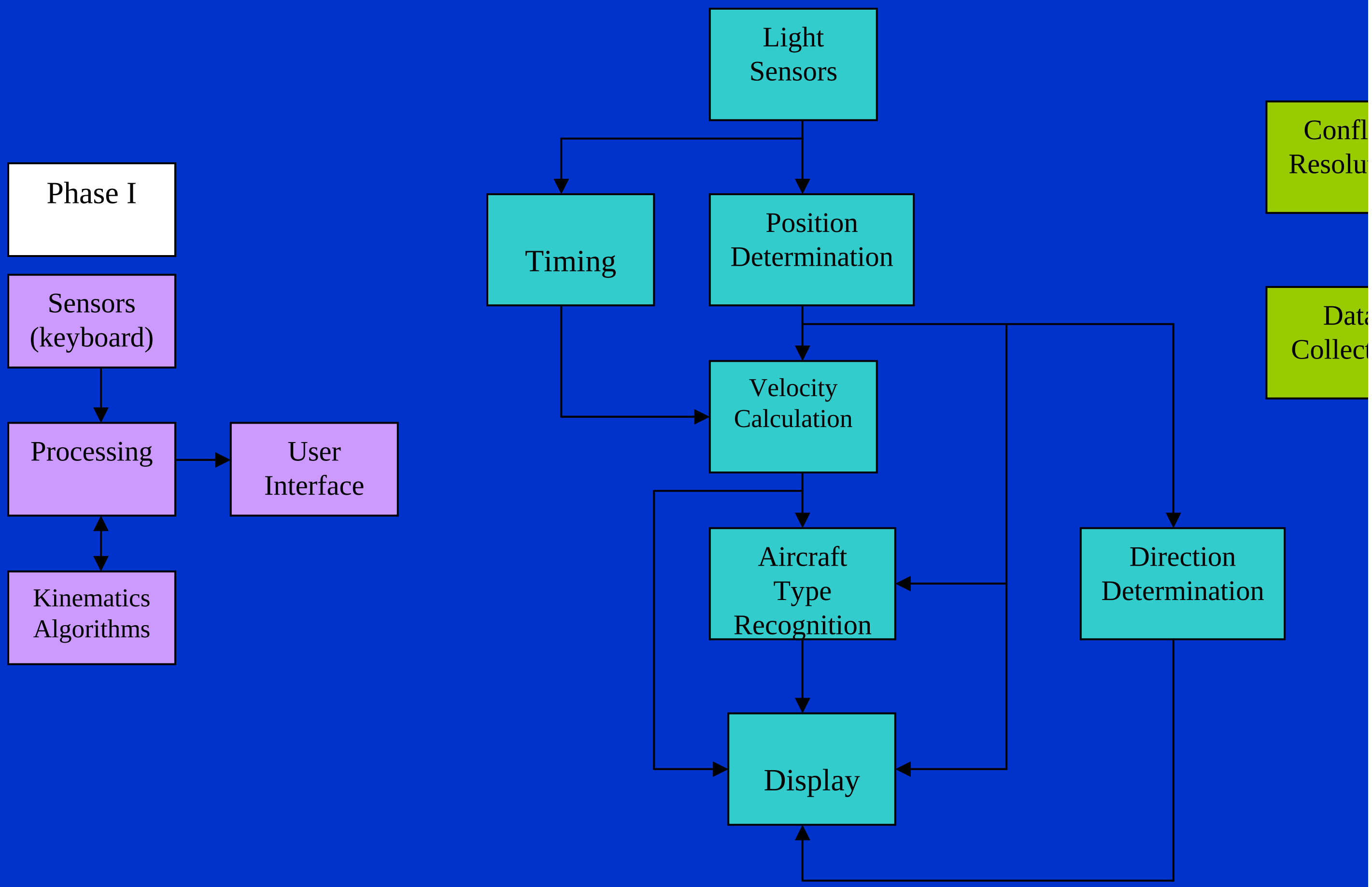
Concept (cont.)



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Concept (cont.)

- This version of software intended solely to allow for development of basic algorithms and to consider further research

- Implemented system would possess following features:
  - Stand-alone: minimal integration, not installed on individual A/C or trucks; does not require vehicle participation
  - Low risk: based on proven principles; system components mature technologies from security industry
  - Low cost: development costs should be low due COTS
  - High payoff: stand-alone automated ground surveillance system providing position, speed, direction, A/C type (and potentially data collection and real-time conflict resolution)

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Kinematic Equations

$$s = \left[d \Big/ \frac{(t(x,1) - t(y,1)) + (t(x,2) - t(y,2))}{2} \right] \cdot c$$

$$x = A,\ y = B : t(A,1) > t(B,1)$$
$$x = B,\ y = A : otherwise$$

$$c = \frac{3600}{5280}$$

$$h = \begin{cases} HBA : t(A,1) \geq t(B,1) \\ HBA - 180 : t(A,1) < t(B,1) \wedge HBA \geq 180 \\ HBA + 180 : t(A,1) < t(B,1) \wedge HBA < 180 \end{cases}$$

$$w = \frac{s}{c} \cdot \left[\frac{(t(A,2) - t(A,1)) + (t(B,2) - t(B,1))}{2} \right]$$

- Classification performed with basic artificial intelligence expert system routine and knowledge base

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Software Design

- Software written in ANSI C++ and compiled using g++ running under Unix
- 100’ sensor spacing chosen to provide large amount of time for more accurate speed calculations
- Also to be larger than largest A/C wheelbase to ensure sensor 1’s beam broken by nose wheel and main mount before nose wheel brakes sensor 2 (necessary because method of inputting data could not distinguish between sensor 1 and 2; this sensor spacing allowed software to assume 1st two signals were always from sensor 1 and 2nd two were always from sensor 2)

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Software Design (cont.)

- Additional assumptions:
  - A/C travels across sensor 1 first, then sensor 2 (closer spacing provides more accurate instantaneous speed calculation; farther spacing provides more accurate averaged time)
  - Vehicles do not stop on, or halfway across, sensors
  - Vehicles always cross perpendicular to sensors (as may be expected, depending on sensor configuration and airport location)

- Due to 1-s resolution and relatively short vehicle transit periods, routine added to protect against “divide by zero” errors in speed calculation; if result calculated were zero, value replaced by 1/2 of timing resolution, i.e., 0.5 s

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Database Population

- Wheelbase data obtained from *Jane’s All the World’s Aircraft 1997-1998*
- None of the dozens of A/C listed and surveyed had same wheelbase – lends credence to concept of being able to distinguish A/C by wheelbase
- No wheelbase measurement listed in any increment smaller than ¼” – indicates that not only should it be possible to classify by wheelbase but that measuring equipment need only have resolution of ¼” to distinguish
- Relatively slow speeds (4, 6, and 10 mph) chosen to provide more accurate timing (due to 1-s resolution of software’s timing calls)

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Database Population (cont.)

- Wheelbases converted to ft. from ft./in. (TOTAL_FEET)
- Averaging each pair of wheelbases in TOTAL_FEET (MEDIAN); used as part of knowledge base in expert system portion of software (“classification” function of class “sensor”)
- “classification” function compares calculated wheelbase to measurements listed in MEDIAN, starting with largest

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Database Population (cont.)

- Once measurement from MEDIAN is found that is less than calculated wheelbase, concludes calculated wheelbase corresponds to shorter of 2 aircraft whose wheelbases were averaged to provide that particular MEDIAN

- TIME_TO_TRAVEL_100_FEET is calculated and listed for 4, 6, and 10 mph to provide values to be applied in determination of time required for each type of A/C’s nose wheel or main mount to travel length of both sensors

- TIME_TO_TRAVEL_the_length_of_the_WheelBase is calculated and listed for 4, 6, and 10 mph; provides values to be applied in determination of time required for each type of aircraft’s nose wheel and main mount to cross one sensor

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Benchmarking and Testing

- All software was expressly designed, engineered, written, updated, verified and validated, tested, and applied as part of research; no off-the-shelf programs or modules used
- After software engineering was complete, each subroutine and the entire program was investigated on a variety of test cases
- During data collection, no programs other than executable under evaluation and those required by OS were either running or open in order to ensure memory leaks, garbage collection, and other operating system self-maintenance did not corrupt or skew results

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Benchmarking and Testing (cont.)

Aircraft is determined to be a Boeing 737-300 (40.83' wheelbase).
Calculated speed is 4.01069 mph.
Measured vehicle wheelbase is 41.1765 feet.
Raw data:
Nosewheel broke sensor 1 at 915721116
Nosewheel broke sensor 2 at 915721133
Mainmount broke sensor 1 at 915721123
Mainmount broke sensor 2 at 915721140
Nosewheel travel time between sensors 1 and 2 was 17 seconds.
Mainmount travel time between sensors 1 and 2 was 17 seconds.
Wheelbase travel time across sensor 1 was 7 seconds.
Wheelbase travel time across sensor 2 was 7 seconds.

Aircraft is determined to be a Boeing 747-400 (84' wheelbase).
Calculated speed is 5.68182 mph.
Measured vehicle wheelbase is 83.3333 feet.
Raw data:
Nosewheel broke sensor 1 at 915721411
Nosewheel broke sensor 2 at 915721423
Mainmount broke sensor 1 at 915721421
Mainmount broke sensor 2 at 915721433
Nosewheel travel time between sensors 1 and 2 was 12 seconds.
Mainmount travel time between sensors 1 and 2 was 12 seconds.
Wheelbase travel time across sensor 1 was 10 seconds.
Wheelbase travel time across sensor 2 was 10 seconds.

Aircraft is determined to be a Boeing C17A Globemaster (65.79' wheelbase).
Calculated speed is 11.3636 mph.
Measured vehicle wheelbase is 66.6667 feet.
Raw data:
Nosewheel broke sensor 1 at 915721486
Nosewheel broke sensor 2 at 915721492
Mainmount broke sensor 1 at 915721490
Mainmount broke sensor 2 at 915721496
Nosewheel travel time between sensors 1 and 2 was 6 seconds.
Mainmount travel time between sensors 1 and 2 was 6 seconds.
Wheelbase travel time across sensor 1 was 4 seconds.
Wheelbase travel time across sensor 2 was 4 seconds.

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Proposed Improvements

- 2 sensors required at each choke point; also provide some smoothing (2 velocities and 2 wheelbases); improvements include noting time tire clears beam, providing secondary set of data – net result 4 velocities with only a software mod, enabling 100% resolution increase

- 3rd sensor would increase number of speed data points from 2 to 6; this hardware mod provides 200% increase in resolution

- Both software and hardware mods provide total of 12 speed data points – 600% resolution increase

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Proposed Improvements (cont.)

- Improving software's timing code to enable $1/10^{th}$ s provides 10-fold resolution increase; $1/100^{th}$ s provides 100-fold increase; initial testing indicates $1/100^{th}$ s provides more than adequate resolution

- Sensors can theoretically resolve down to wavelength.
  - Sensors from security and surveillance industry are in infrared range of 0.75 microns (near-IR) to 1 mm (extreme IR)
  - Thermal imaging takes place at 8-10 microns (far IR)
  - Chosen sensor will most likely be lower, probably with the majority of lasers (including rangefinders and designators) in near-IR at 0.75 to 3.0 microns

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Additional Observations

- Sensor placement possible source of error – modern surveying techniques (DGPS) should keep these errors to 3 mm or less
- Given timing, positioning, and resolution errors and solutions, a fully integrated system should be able to resolve wheelbase well within desired ¼” (better than manufacturing tolerances?)

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Conclusions

- Tandem optical sensors:
  - Concept described
  - Kinematics formulation
  - Initial software
  - Laboratory test results

- Prototype software for development of basic algorithms and as proof-of-concept

- Future use as:
  - Airport ground surveillance system (multiple sensors as airport's sole ground surveillance)
  - Augmentation to existing systems (fill-in blind spots, enable vehicle classification, mitigate multipath, corroborating data)
  - Geospatial and classification data for data collection or as runway incursion prevention system

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